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STUDIES ON Al6061/Al_2O_3 AND GRAPHITE HYBRID METAL MATRIX COMPOSITES

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ABSTRACT

Aluminum MMCs are preferred to other conventional materials in the fields of aerospace, automotive and marine applications owing to their improved properties like high strength to weight ratio, good wear resistance etc. In the present work an attempt has been made to synthesize metal matrix composite using 6061Al as matrix material reinforced with ceramic Al_2O_3 and Graphite particulates using liquid metallurgy route in particular stir casting technique. The addition of reinforcement alumina is maintained 10% as constant and the Graphite is varied as 3%, 6% and 9%. For each composite, reinforcement particles were preheated to a temperature of 200° and then dispersed in steps of three into the vortex of molten 6061Al alloy to improve wettability and distribution. Micro-structural characterization was carried out for the above prepared composites by taking specimens from central portion of the casting to ensure homogeneous distribution of particles. Hardness, tensile and wear properties of the prepared composite were determined before and after addition of Al_2O_3 and Graphite particulates. Micro-structural characterization of the composites has revealed fairly uniform distribution and some amount of grain refinement in the specimens. Further, the hardness, tensile strength and wear resistance properties are higher in case of composites when compared to unreinforced 6061Al matrix.

KEYWORDS: MMC's, Al_2O_3 Particulates, Graphite, Al 6061, Stir-Casting

INTRODUCTION

Metal–matrix composites (MMCs) are most promising materials in achieving enhanced mechanical properties such as: hardness, Young's modulus, yield strength and ultimate tensile strength due to the presence of micro-sized reinforcement particles into the matrix. Aluminum-matrix composites (AMCs) reinforced with discontinuous reinforcements are finding increased use in automotive, military, aerospace and electricity industries because of their improved physical and mechanical properties. Among Al-alloys, 6061Al-alloy is widely used in engineering applications such as transport and construction sectors where superior mechanical properties like tensile strength, hardness etc., are essentially required.

The mechanical properties of MMCs are very sensitive to the method of processing being used. Considerable improvements may be achieved by applying science-based modeling techniques to optimize the processing procedure. Several techniques have been employed to prepare the composites including powder metallurgy, melt techniques and squeeze casting. However, powder metallurgy appears to be the preferred process in view of its ability to give more uniform dispersions. Hot extrusion is generally used as post-treatment to take the advantages of applying compressive forces and high temperatures, simultaneously [1] [2] [3].

Although powder metallurgy produces better mechanical properties in MMCs, liquid state processing has some important advantages. They are as: better matrix-particle bonding, easier control of matrix structure, simplicity, low cost of

processing, nearer net shape and the wide selection of materials. Liquid state fabrication of MMC's including two methods which depend on the temperature at which the particles are introduced into the melt. In melt stirring process, the particles are incorporated above the liquidus temperature of the molten alloy, while in compo-casting method the particles are incorporated at the semi solid slurry temperature of the alloy. In both processes, the vortex is used for introducing reinforcement particles. However, the melting process has two major problems firstly, the ceramic particles are generally not wetted by the liquid metal matrix, and secondly, the particles tend to sink or float according to their density relative to the liquid metal. Wettability can be defined as the ability of a liquid to spread on a solid surface and it represents the extent of intimate contact between liquid and solid. Consequently, it results in poor dispersion of the ceramic particles, high porosity and low mechanical properties of the composite The aim of present study is to synthesize 6061Al- Al_2O_3 particulate MMC by stir casting method. In order to improve wettability and distribution of reinforcing particles a novel three stage mixing combined with preheating of the reinforcing particles is being adopted and also to investigate the effects of different factors such as:

- Weight percentage of the particles
- Fabrication process on the microstructure, mechanical and wear properties of the composites.

EXPERIMENTAL DETAILS

The following section highlights the material, its properties and methods of composite preparation and testing.

Materials Used

The matrix material for the present study is Al6061. Al_2O_3 and Graphite is used as reinforcement material in the preparation of composites. The chemical composition of matrix material is as shown in Table1. The particles size of the reinforcing material was about 80-100 µm. Table 2 gives the properties of Matrix and Reinforcing materials used in the present study taken from the literature.

Table 1: The Chemical Composition of Al6061 Alloy by wt%

Elements	Si	Fe	Cu	Mn	Ni	Pb	Zn	Ti	Sn	Mg	Cr	Al
Percentage	0.43	0.7	0.24	0.139	0.05	0.24	0.25	0.15	0.001	0.802	0.25	Balance

Table 2: The Properties of Matrix and Reinforcing Materials Used in the Study

Material/ Properties	Density gm/cc	Hardness (HB500)	Strength (Tensile/ Compressive) MPa	Elastic Modulus GPa
Matrix – 6061 Al	2.7	30	115 (T)	70-80
Reinforcement Al_2O_3 Particle	3.69	1175	2100 (C)	300
Reinforcement Graphite particle	1.92	1021	90 (T)	14

Preparation of Composites

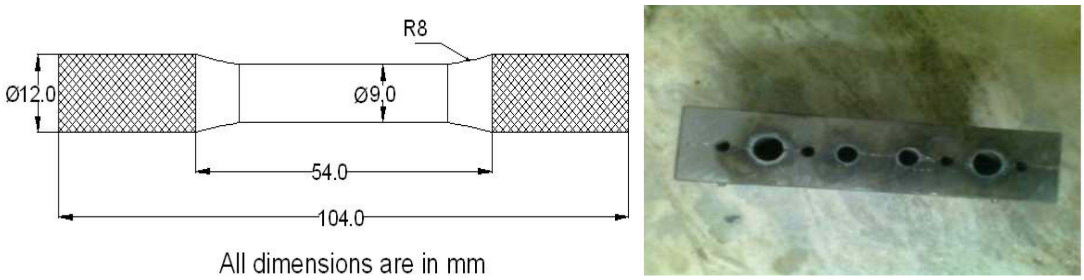
The liquid metallurgy route (stir casting technique) has been adopted to prepare the cast composites as described below. Preheated Al_2O_3 and Graphite particles of laboratory grade purity of particle size 80-100µm were introduced into the vortex of the molten alloy after effective degassing using solid hexachloroethane (C_2Cl_6). Before introducing reinforcement particles into the melt they were preheated to a temperature of 250^0C. The extent of incorporation of Al_2O_3 and Graphite particles in the matrix alloy was achieved in steps of 3. i. e Total amount of reinforcement required was

calculated and is being introduced into melt 3 times rather than introducing all at once. At every stage of before and after introduction of reinforcement particles, mechanical stirring of the molten alloy for a period of 10 min was achieved by using Zirconia-coated steel impeller. The stirrer was preheated before immersing into the melt, located approximately to a depth of 2/3 height of the molten metal from the bottom and run at a speed of 200 rpm. A pouring temperature of 750^0C was adopted and the molten composite was poured into permanent cast iron moulds. Thus composites are made with base material Al6061, Al6061+10% $Al_2O_{3,}$ Al6061+10% Al_2O_3+Gr 3% and by varying Graphite up to 9% in the interval of 3%, were obtained in the form of cylinders of diameter 12.5mm and length 125mm [4], [5].

Testing of Composites

To study the microstructure of the specimens the central portion of the casting was cut by an automatic cutter device. The specimen surfaces were prepared by grinding through 300, 600 and 1000 grit papers and then by polishing with 3 μm diamond paste. Microscopic examination of the composites was carried out by optical microscopy. To investigate the mechanical behavior of the composites the hardness and tensile tests were carried out using Zwick and computerized uni-axial tensile testing machine as per ASTM standards, Figure 1. represent the dimensions of the mould and specimen used for tensile studies.

The Micro-Vickers hardness values of the samples were measured on the polished samples using diamond cone indentor with a load of 20N. Hardness value reported is the average value of 100 readings taken at different locations on the polished specimen. For tensile results, test was repeated three times to obtain a precise average value.



(a) **(b)**

Figure 1: The Details of (a) Dimensions of the Tensile Specimen (b) Mould for Producing Composites

RESULTS AND DISCUSSIONS

Fabrication of metal–matrix composites with alumina particles by casting processes is usually difficult because of the very low wettability of alumina particles and agglomeration phenomena which results in non-uniform distribution and weak mechanical properties. In the current work, Al6061 aluminum alloy matrix composites with micro size alumina and Graphite particles were produced by stir casting method [6]. The magnitude of alumina powder used in the composites is 10% and Graphite starting from is 3%, 6% and 9% . The optical micrographs of the 6061-Al alloy with 10wt. % alumina particulates and 3%, 6%, 9% of varying Graphite percent were shown in Figure 3(a-e).

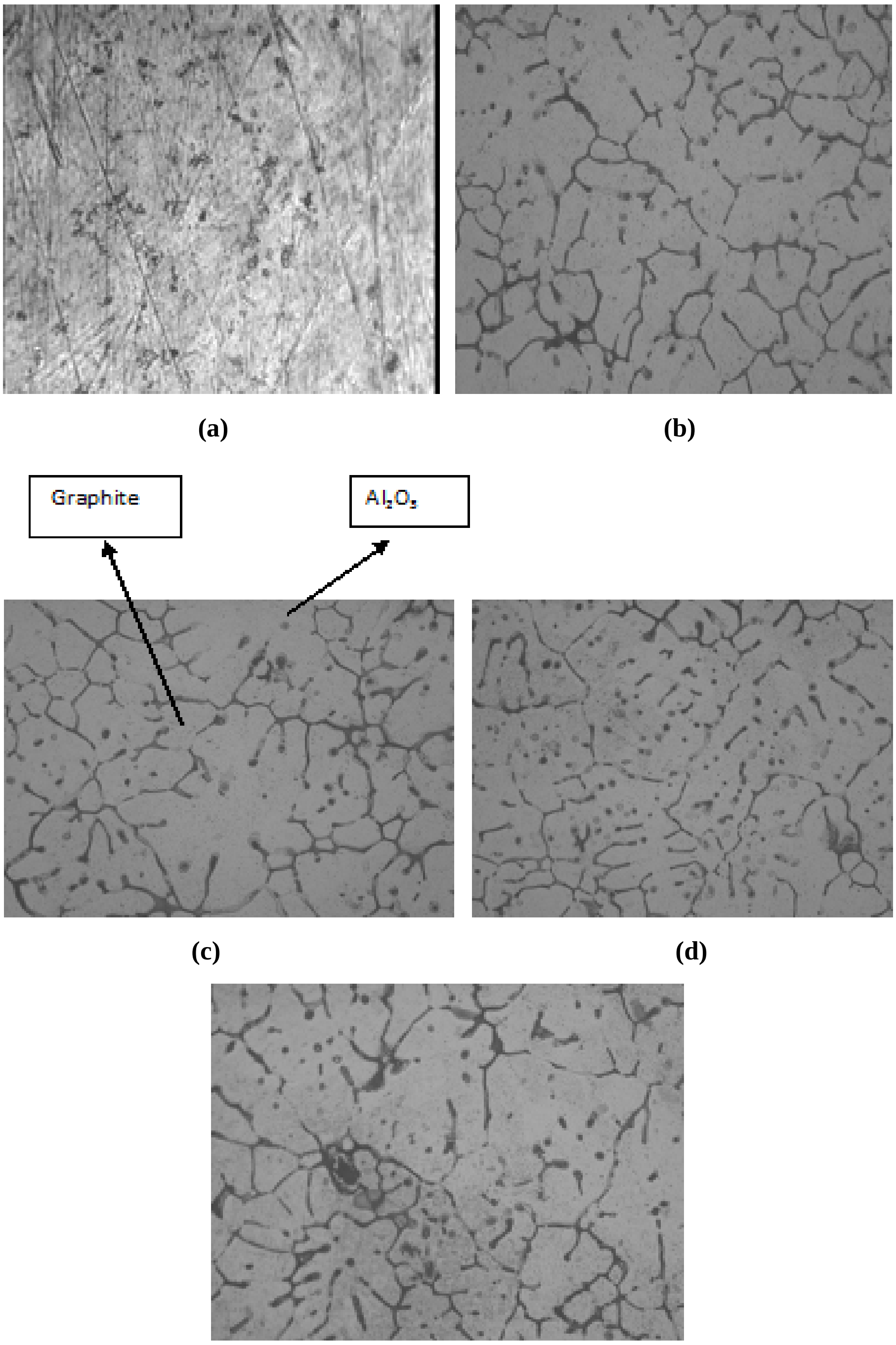


Figure 2 a-e: The Optical Microphotographs (a) As-Cast (b) with 10% Al_2O_3 (c) with 10% Al_2O_3 +3%Gr (d) with 10% Al_2O_3 +6%Gr (e) with 10% Al_2O_3 +9%Gr

The microstructure of as cast 6061Al and 6061Al with 10 wt% Al_2O_3 with varying Graphite percentage are represented in Figure 2a-e. The microstructure of the prepared composites contains primary α-Al dendrites and eutectic silicon, while Al_2O_3 and Graphite particles are separated at inter-dendritic regions and in eutectic silicon. The stirring of melt before and after introducing particles has resulted in breaking of dendrite shaped structure into equiaxed form, it improves the wettability and incorporation of particles within the melt and also it causes to disperse the particles more uniformly in the matrix. Figure 2b-e reveals the distribution of alumina particles in different specimens and it can be

observed that there is fairly uniform distribution of particles and also agglomeration of particles at few places were observed in both the composites reinforced with 9wt.% Graphite. The microphotographs also indicate that the Al_2O_3 and Graphite particles have tendency to segregate and cluster at inter-dendritic regions which are surrounded by eutectic silicon (Figure 2b–e). Further, the micrographs show that grain size of the reinforced composite (Figure 2.a-e) is smaller than the alloy without alumina particles (Figure 2a) because, Al_2O_3 and Graphite particles added to melt also act as heterogeneous nucleating sites during solidification.

Hardness Measurement

The micro hardness tests conducted on Al 6061 and Al6061 composite containing 10% of Al_2O_3 and 3%, 6% and 9% of varying Graphite particles are prepared and the results are represented in Figure3. The Micro-Vickers hardness were measured on the polished samples using diamond cone indenter with a load of 100g and the value reported is average of 100 readings taken at different locations. A significant increase in hardness of the alloy matrix can be seen with addition of Al_2O_3 particles. A hardness reading showed a higher value of hardness indicating that the existence particulates in the matrix have improved the overall hardness of the composites. This is true due to the fact that aluminum is a soft material and the reinforced particle especially ceramics material being hard, contributes positively to the hardness of the composites. The presence of stiffer and harder Al_2O_3 reinforcement leads to the increase in constraint to plastic deformation of the matrix during the hardness test. Thus increase of hardness of composites could be attributed to the relatively high hardness of Al_2O_3 itself. Though adding Graphite makes material ductile but the hardness does not decrease below the base material.

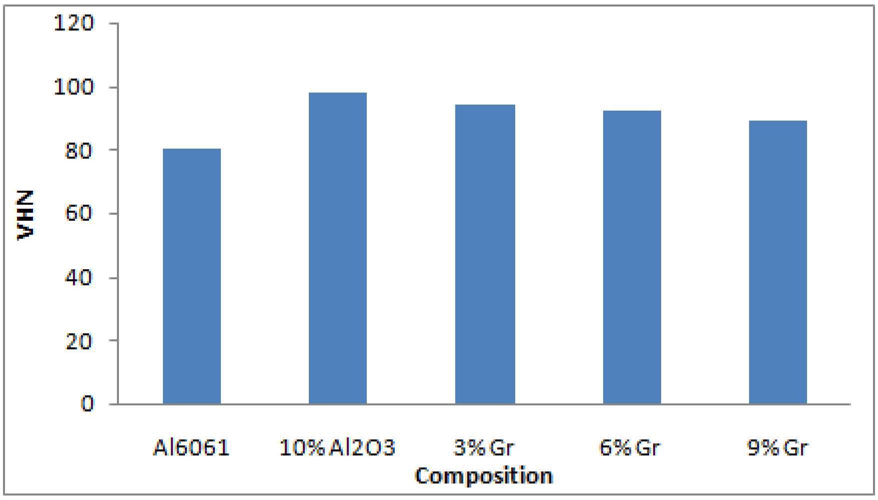


Figure 3: Showing the Variation in VHN for all the Mentioned Compositions

Tensile Properties

To investigate the mechanical behavior of the composites the tensile tests were carried out using computerized uni-axial tensile testing machine as per ASTM standards. Three test specimens were used for each run. From the test it is inference that the improvement in ultimate tensile strength in base matrix with 10% alumina is maximum, this is due to the fact that alumina is a hardest ceramic which on reinforcement forms a stronger composite. i.e. the load applied is shared between aluminum base matrix and alumina, as said above when the load is shared by hardest particle alumina, it resists deformation resulting in higher stress withstanding capability. In further as the Graphite percentage is varied ductility

increases which also contribute in higher plastic region and hence the increase in ultimate and yield strengths are represented in Figure 4.

Table 3: The Results of Tensile Test Specimens

Sl No.	Composition	Tensile Strength (MPa)	Yield Strength (MPa)	%Improvement in Tensile Strength
1	Al6061	128	116	-
2	Al6061+10wt%Al_2O_3	164	152.89	28.12
3	Al6061+10wt%Al_2O_3+3%Gr	153	138.41	19.53
4	Al6061+10wt%Al_2O_3+6%Gr	158	140.38	23.43
5	Al6061+10wt%Al_2O_3+9%Gr	160	142.37	25

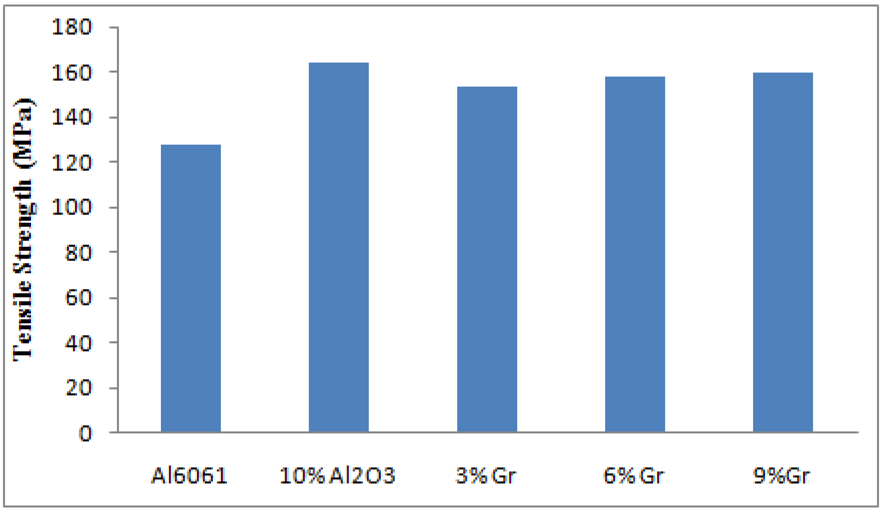


Figure 4: The Variation in Tensile Strength for Different Compositions of Al6061 with Al_2O_3 and Graphite Particles

Wear Properties

Wear is a process of material removal phenomenon [7] [8]. The prepared 6061Al with10% Al_2O_3 and varying weight percentage of Graphite composites were subjected to wear test under dry sliding condition. The test was conducted on 8mm diameter and 25mm long cylindrical specimens against a rotating En-32 steel disc. The tangential friction force and wear were monitored with the help of electronic sensors. These two parameters were measured as a function of load and sliding distance. For each type of material, tests were conducted at 20N nominal load and varying sliding speed at 400rpm and 600rpm, wear tests were carried out at room temperature without lubrication and the Wear results are represented in Figure 5.

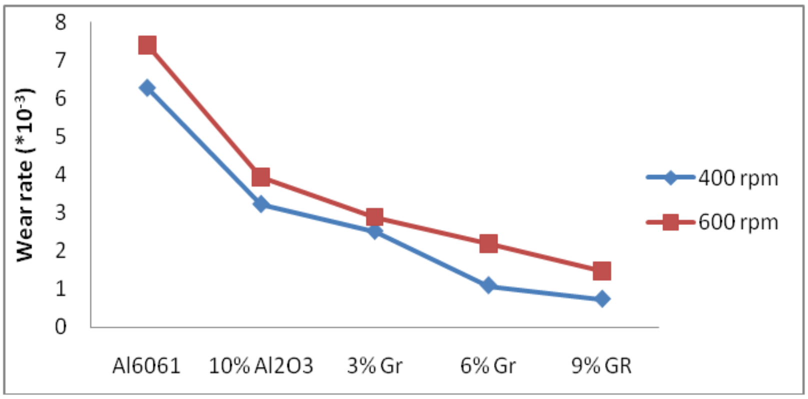


Figure 5: The Wear Results for the above Mentioned Compositions at 400 and 600 rpm

CONCLUSIONS

- From optical microscopy results it is found that addition of magnesium at 0.1 ratio to the reinforcement increases the wettability and dispersion of the reinforcement particles.
- Tensile strength of prepared composites is higher in case of composites, when compared to cast 6061Al.
- Addition of 10wt% Al_2O_3 increases the tensile strength considerably with respect to base matrix Al6061. Whereas the addition of Graphite particulates doesn't vary the tensile strength much with respect to Al_2O_3 added composition.
- Hardness number of the prepared composites is higher than the base 6061Al-alloy.
- Addition of 10wt% Al_2O_3 increases hardness considerably, whereas the addition of Graphite particulates decreases the hardness and increasing in ductility, The cumulative effect results higher than the Al6061 alloy.
- Addition of 10wt% Al_2O_3 decreases the wear rate compared to base Al6061 alloy. The Cumulative effect of 10wt% Al_2O_3 and Graphite particulates with varying percentage further decreases the wear rate.
- As the addition of Al_2O_3/Graphite particulates increases tensile strength and is decreasing the wear rate, these composites can be used for journal bearings and antennas in aircrafts.

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